Sources of Satellite Anomalies and Effects and their Mitigation

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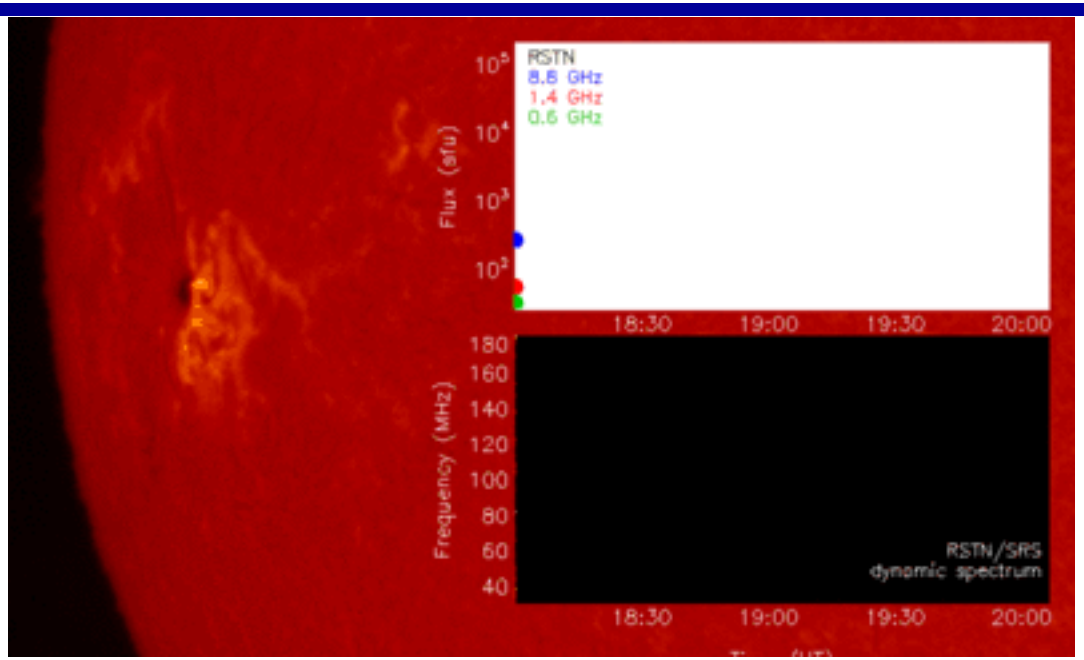
Sources and Types of Satellite Anomalies

- **Sources**
  - **Spacecraft Surface Charging**
    - May cause electrostatic discharges (ESDs) and arcing on solar arrays, power cables
    - Caused by electrons of 5-50 keV in GEO, 2-20 keV in PEO, or high voltage arrays in LEO
  - **Deep Dielectric Charging**
    - May cause arcing internally to spacecraft
    - Caused by total dose of electrons of 200 keV-3 MeV, protons of > 10 MeV, or prompt SEPs or X-rays
    - Single Event Upsets (SEUs) caused by ionization trail of single high energy particles in sensitive electronics
- **Types**
  - **Transient effects** (bit flips in electronics, EMI, causing spurious commands or software upsets)
  - **Permanent damage** (arcs, ESDs, and MCP saturation, may damage electronics, and/or cause power cabling or solar array failure)

Space Weather Anomaly Sources - Flares and Radio Bursts

Stephen White



- Flares: prompt impact on HF radio comms due to ionization in D layer by X-rays
- Radio bursts: can knock out GPS, interfere with comms, radar
- Large event of 2006 Dec 06: knocked out GPS for 20 minutes, affected cell phone reception, occurred after impulsive phase of flare. An issue for increased use of UAVs, aircraft landing position
- Solar interference is important for systems with wide beams
- High microwave, mm frequencies also see large bursts
- Flare prediction is an active area, helped by new ability to sense far-side activity

Space Weather Anomaly Sources - Coronal Mass Ejections

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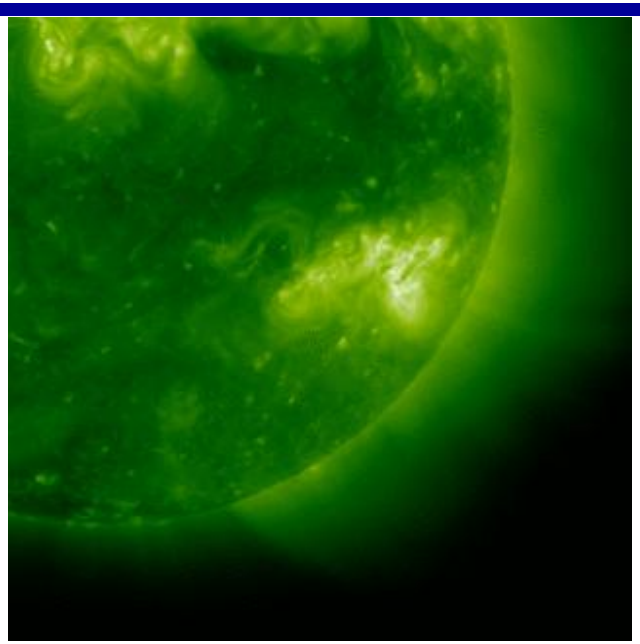
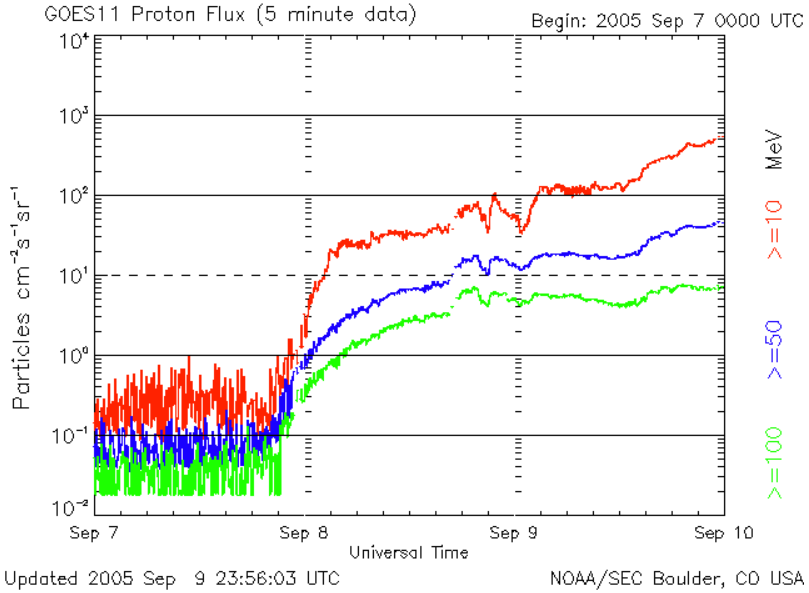


- Coronal mass ejections (CMEs): large eruptions of mass at 1000 km/s, generally associated with flares, take 1-3 days to arrive at Earth, generate magnetospheric storms
- Need to know whether they will strike Earth, and what the magnetic field orientation is
- Compression of magnetosphere can accelerate particles, causing satellite anomalies, and can affect power systems, radiation belts, ionospheric communication conditions
- May also be progenitors for solar energetic particles
- Solar wind: “corotating interacting regions” occur when there is a transition at the Earth’s magnetosphere in the type of solar wind hitting it, can cause storms and (> 2 MeV) “killer electrons”

Space Weather Anomaly Sources - Solar Energetic Particles

Stephen White



- Energetic particle events: protons with energies >> 10 MeV, radiation hazard for astronauts and polar flights, affect satellite electronics, polar cap absorption in ionosphere
- Can come from flares or CMEs, can arrive within 10 minutes of a flare
- **v**×**B** forces in geomagnetic field control entry of SEPs: more important at poles than equator
- Largest events (ground level enhancements, or “GLEs”) are seen by neutron monitors: high-energy protons produce neutrons by nuclear interactions in the atmosphere, can reach detectors on the ground
- Prediction: similar to flares, but not all large flares produce SEPs

A Few Anomalies and Their Probable Causes

- **Anik E-1 and E-2 (1994) – deep dielectric electron charging during severe geomagnetic storm led to communications disruptions lasting for days**
- **Tempo-2 and PAS-6 (1997) – sustained arcs from geomagnetic substorm ESDs caused complete LOM**
- **ADEOS-2 (2004) – micrometeoroid strike during auroral charging event caused complete LOM (loss of mission)**
- **Galaxy 15 (2010) – ESD caused electronics problem coming out of eclipse during severe geomagnetic substorm, recovered after 8 months adrift**
- **DMSP-15 (2011) – computer upset after large total internal dose from X-class flare X-rays**
- **Echostar 129 (2011) – temporary (24 hr) pointing/positioning loss after huge peak in GOES > 2 MeV (“killer’) electrons**
- **SkyTerra-1 operated by LightSquared (March 7, 2012) – knocked out for 3 weeks due to SEU caused by energetic protons & CME**
- **Other March 2012 anomalies – Venus Express, HughesNet Spaceway 3**

Space Situational Awareness

- A key goal for DoD – 2010 National Space Policy
- DoD must determine whether anomalies are due to the Space Weather or to hostile actions
- Operations may be affected by efforts to prevent space weather-related outages
- Space Weather prediction and real-time anomaly resolution very important

How to Design to Prevent Space Weather Charging-Related Anomalies

- Harden all vital electronics and place in well-shielded Faraday cage
- Coat all surfaces with grounded conductors
- No ungrounded or unshielded conductors (Galaxy 15 failure mechanism, NASA TP-2361)
- Design for more secondary electron emission and less photoemission (per Shu Lai, 2011, “Spacecraft Charging”)
- Use a well validated spacecraft charging code – SPIS (ESA), MUSCAT (KIT), or Nascap-2k.
- Design and test arrays to prevent ESDs and sustained arcs (Tempo-2 failure mechanism, NASA-STD-4005, NASA-HDBK-4006, ISO 11221)
- Design spacecraft to prevent deep dielectric discharges (NASA-HDBK-4002A)
- Fly charge monitors and charging mitigation systems

Operations to Mitigate Space Weather-Related Anomalies

- Upload software that resets after SEUs (would have mitigated Galaxy 15, SkyTerra-1)
- Monitor space environments and charging predictions (Real-time Nascap-2k*, SWPC, SEAESRT, etc.)
- When severe Space Weather is predicted, turn off sensitive electronics if possible (thrusters, focal-plane arrays, MCPs, etc.)
- Shunt arrays (or feather into the wake) when severe charging is likely and/or when coming out of eclipse

* In testing and preparation